9. Coastal Systems

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9.1 Introduction

This assessment addresses coastal systems in the broader Bering Sea region, including mainland coasts of both Russia and North America from the Lena River to the MacKenzie River Delta, the entire coastline of the Bering Sea and the remaining coastline of Alaska adjacent to the Gulf of Alaska and Southeast Alaska. We define the coastal zone for the purposes of this assessment as the zone typically used by residents of coastal communities. We note that this definition is broader than that used for management of the coastal zone by state and federal agencies but we believe this definition is more appropriate for addressing dynamics of coastal systems associated with global change.

Topography and geomorphological processes vary substantially across this region. Much of the coast of the Bering Sea is dominated by river deltas and shallow bays and estuaries. A dominant deltaic feature of the region is the Yukon-Kuskokwim (Y-K) Delta, formed by alluvial deposits of the Yukon and Kuskokwim Rivers, which covers 79,280 km^2 of treeless tundra. Much of the Y-K Delta has extremely shallow topographic gradients. In contrast, much of the coast of western and northwestern Alaska is characterized by mountains and bluffs. On the north slope, topographic gradients are relatively shallow but because the coastline is not primarily of deltaic origin and tidal amplitude is small, coastal processes may be relatively less important on the north slope compared to much of the remainder of Alaska.

The Alaskan coast of the Bering Sea supports some of the highest concentrations of indigenous people living primarily a subsistence lifestyle at high latitude. Large concentrations of people also live in a few communities along the coasts of the Chukchi and Beaufort Seas. High densities of people depending on subsistence resources are undoubtedly associated with high productivity of foods in both terrestrial and marine habitats. Anadromous fish represent the principal source of both protein and calories for people in much of this region, although marine mammals play a much greater role on the Arctic coast. Indigenous people in this region have had significant contact with European/western cultures for variable periods, which combined with coastal and marine topography, results in substantial variation in economic opportunity and importance of cash income to overall economic conditions throughout the area.

One approach to regional impact assessment is to delineate potential disturbances to a region, characterize potential responses to such disturbance, and identify gaps in understanding of system dynamics that inhibit predictions of response to disturbance. Many potentially important disturbances in the Bering Sea coastal region fit within the broad context of global change. These include:

- climatic influences on tidal flooding, erosional and depositional processes;
- climatic warming and related effects on sea ice, snow cover, timing of spring thaw, and primary and secondary productivity;
- population dynamics and socioeconomic changes among people living in the Bering Sea region;
- human induced effects on migratory stocks (e.g., marine mammals, salmon, waterfowl) that use the Bering Sea region seasonally.

We focus on changes likely to occur within a time frame of a few decades, which is the frame of reference most relevant to stakeholders.

9.2 People of the Bering Sea Coast

The highest concentration of native people in Alaska occurs in coastal areas. Approximately 58,000 people live on the North American side of the Bering Sea, of which 60% are members of one of three Native populations. Major population groups in the greater Bering Sea region include Yupik, Aleut, and Inupiaq. The population on the Y-K Delta has doubled since 1960 (Wentworth 1994) and is among the fastest growing populations in the world. People living in the Bering Sea coastal region are distributed primarily in villages of 100-1,000 people, with a few regional centers of 2,000-4,000 people. None of these towns or villages occur on the road system, which increases expense of distribution of goods and services.

Potential for employment varies among areas. Commercial fishing provides about 10% of personal cash income in the Bristol Bay area, while oil development either directly or indirectly accounts for 50% of personal cash income on the North Slope. Employment is extremely limited on the Y-K Delta, with most employment associated with federal or state government or native corporations (U. S. Bureau of Economic Analysis). Limited employment is derived from commercial fishing. In 1992, the Community Development Quota (CDQ) program was initiated, allocating 7.5% of the catch from Bering Sea pollock and cod fisheries to villages on the Bering Sea coast. Recently, the program was expanded to other Bering Sea species, but it is currently scheduled to sunset in 1998. Funds from CDQs are contributing to economic development in the Bering Sea region.

Because of limited potential for employment in many coastal areas of the Bering Sea region much of the cash economy depends heavily on government transfers. Recent welfare reform legislation is of concern in the region because of limited potential for wage employment.

Relatively early stages of development of a cash economy means that people in the Bering Sea region depend on subsistence hunting and fishing for the majority of total calories (Schroeder et al. 1987). Therefore, changes in these resources will likely have a large impact on livelihoods of people living in the region. It is important to emphasize, however, that the modern subsistence lifestyle is heavily dependent on substantial cash income.

9.3 Future Changes

Numerous direct and indirect effects of global change are expected to influence the coastal zone of the Bering Sea region. Climate change is expected to produce substantially warmer temperatures in the Bering Sea region (Weller et al. 1995). Warming over the past 2 decades has substantially increased permafrost temperature and depth of thaw. Increased thawing in coastal areas will undoubtedly increase erosion of coastal peat. Erosion will be exacerbated by rising sea level and increased storm frequency and intensity forecast for the Bering Sea.

Coastal Processes and Erosion

Coastal areas of the Bering Sea region will be highly susceptible to changes resulting from both climate change and human induced changes. Low topographic relief over much of this area, combined with normally high amplitude tide cycles and high energy storm systems create the potential for substantial impacts on landscapes from slight increases in sea level and storm frequency. For example coastal areas on the Y-K Delta have been inundated nearly annually by storm surges during the fall period in the mid 1990's and in August during both 1995 and 1996. These fall storms deposit substantial sediment loads, significantly modifying coastal landscapes. In addition, these large storms likely increase erosion and ice scouring (fall storms). The storm in fall 1996 nearly flooded some houses in the coastal village of Hooper Bay. Storms during the normal nesting season can destroy nearly the entire nesting effort of several waterfowl populations.

Tidal amplitude along the coast of the Y-K Delta can be as large as 5 m between seasonal high and low tides. Large tidal amplitude produces high hydrological energy along the coast and well into large rivers in the area. High hydrological energy associated with much of the coastline of the Y-K Delta is associated with high rates of erosion of exposed peats along much of this coastline. Aerial photography shows disappearance of up to 500 m of coastline in some locations, primarily exposed points, between 1950 and 1984. At Punyrat Point, 20 km south of Hooper Bay, 50 m disappeared between 1988 and 1993 (Sedinger pers. obs.). Erosion is also rapid on large former distributaries of the Yukon River, such as the Kashunuk and Manokinuk Rivers. At some points as much as 10 m of river bank have disappeared in a single growing season (R. M. Anthony pers. comm.). Erosion has forced movement of the village of Newtok in the central Y-K Delta. Such effects are likely to be especially pronounced on the Bering Sea coast itself because of generally shallow topographic gradients and high energy associated with storms in the Bering Sea. Increased frequency and intensity of storms in the Bering Sea, especially when coincident with increased sea level and seasonal high tides, is likely to increase erosion along the Bering Sea coast.

Erosion is also occurring along the north slope of Alaska. While tidal amplitude is reduced on Alaska's north slope, erosion may be substantial because of large seasonal storm surges. Erosion is exacerbated by thawing of permafrost and additionally by increased fetch associated with reduced sea ice.

Marine currents within the Bering Sea generally flow counterclockwise (Nelson et al. 1981) resulting in northerly flow along the Bristol Bay and Y-K Delta coasts (see Fig. 7.1, Chapter 7). These currents also produce generally northerly currents through the Bering Strait. Currents in coastal areas determine coastal sediment transport and the origin of terrestrial inputs into the Bering Sea. These currents also influence salinity because of their role in distributing fresh water inputs from the major rivers in the region, especially the Yukon and Kuskokwim Rivers.

Hydrological events vary seasonally throughout the region because of strong seasonal weather patterns and precipitation. Peak discharge from major rivers occurs in spring associated with snow melt in interior watersheds (McDowell et al. 1987). Severe flooding associated with high runoff and ice dams is common in villages along major rivers. Similarly, ocean currents vary seasonally. Sea ice slows currents within the Bering Sea, while strong wind driven storm surges are common during fall (McDowell et al. 1987). Fall storm surges may inundate coastal areas up to 16 km inland (Dupre 1980) and have caused famine in historic times because of the destruction of food caches. High hydrological energy associated with flooding events also produces the greatest risk of distribution of pollutants from industrial accidents.

Sediment deposition occurs at multiple spatial scales and plays an important role in habitat creation and landscape evolution. A series of barrier islands, resulting from coastal transport, extend along the central Y-K Delta coast. Large depositional zones coincide with bends on all rivers and sloughs. Deposition combined with erosion brings about rapid channel migration on time scales of decades to centuries. Rapid channel migration could impact village infrastructure as in the case of the village of Newtok. Channel migration also can destroy historical and archaeological sites. The Kavinik site near Chevak is rapidly eroding, and plans are underway to excavate the site to salvage artifacts. In general, dynamic landscape processes limit the maximum possible age of archaeological sites on the Y-K Delta.

Sediment is also deposited on terrestrial landscapes by storm tides, especially in fall. T. Jorgenson (unpublished) has recorded up to 4 cm of sediment deposited in coastal vegetation from a single flood event. Sediment loads decrease steadily along a transect extending inland from the coast. Sediment deposition undoubtedly plays an important role in maintaining levees along channels. Sediment deposits likely increase soil aeration and reduce soil water content, which in turn, influences plant distribution. These levees are important foraging habitats for geese because they support arrowgrass, a key food plant for geese.

Inundation of low lying coastal areas is also of concern, particularly along the Y-K Delta where much of the coastal area is currently subject to tidal inundation during storms. Sea level increase of only a few centimeters will inundate thousands of square kilometers of the coastal fringe of the Y-K Delta as well as increasing frequency of inundation by large storms in additional areas.

Sea Ice

Because of the importance to subsistence activities, changes of sea ice distribution are of special concern to residents of coastal areas in the Bering Sea region. Hunting of marine mammals occurs directly from shorefast ice in spring and distribution of ice influences migration patterns of marine mammals. There is substantial concern that retreat of sea ice from Alaska's north slope will enable whale migration to occur farther offshore, making whales unavailable to subsistence hunters (T. Albert 1992 unpubl. memorandum).

Extent of sea ice in the Bering Sea during winter has declined over the last 2 decades, which reflects an apparent state change in sea-surface temperature of the Bering Sea in the late 1970's. Southern limit of sea ice frequently extended as far south as Nunivak Island before the state change but only infrequently since. Distribution of winter ice influences distribution of marine mammals, and ice retreat in recent years is reducing access to marine mammals by subsistence hunters in the region. Ice conditions during spring influence timing of spring snowmelt and initiation of plant growth. Timing of snowmelt has important consequences for productivity of geese, an important subsistence resource.

Subsistence Resources

We have already discussed potential impacts of changes in sea ice distribution on hunting of marine mammals in coastal areas. Numerous other potential impacts on harvest of subsistence resources are likely to be associated with global change.

With few exceptions (e.g., bowhead whales and some waterfowl populations) subsistence harvest throughout the region is not surveyed annually, but total subsistence of fish in villages at the mouth of the Yukon River ranged from 1,983 lbs. per household for the villages of Emmonak and Kotlik to 7,633 lbs. for Sheldon Point (Wolfe 1981). Chum salmon were the predominant fish species in the subsistence harvest. Harvest of salmon on the Yukon and Kuskokwim Rivers and in Bristol Bay is regulated and monitored because of commercial value of these fisheries. No monitoring of subsistence fisheries on the central coast of the Y-K Delta occurs because these fisheries have little commercial value. Salmon in rivers on the central Y-K Delta coast, however, likely originate in the Yukon River and are shared with subsistence and commercial fishermen in the upper Yukon River (Criddle 1996). Furthermore, growth of the human population on the Y-K Delta could be increasing subsistence salmon harvest. This should be of interest because residents of the Y-K Delta rely on these fisheries.

Better data exist on harvest of migratory birds because of concern about these populations (O'Neill 1979, Raveling 1984) and because of international agreements relating to their protection. U.S. Fish and Wildlife Service has conducted harvest surveys in villages on the Y-K Delta since 1985 (Wentworth 1994) and a statewide summary of subsistence harvest of some waterfowl species was conducted in 1995 (Wolfe and Paige 1995). Klein (1966) conducted the first systematic survey of harvest of migratory birds on the Y-K Delta. Waterfowl harvests were generally lower in the 1980's (Wentworth 1994) than during the 1960's. It is unknown whether decline in harvest resulted from lower waterfowl population levels or changed hunting behavior. Waterfowl harvests since the mid 1980's have been proportional to population size (Sedinger 1996), suggesting that availability of waterfowl to hunters influences harvest.

Waterfowl are among the most closely monitored populations because they are of international importance and are a federal government responsibillty. Therefore, waterfowl are surveyed annually in most important breeding and migration areas. Population trend data from these surveys extend back to at least the 1960's. Populations of geese declined substantially in the 1960's and 1970's, owing to overharvest on both wintering and breeding areas (O'Neill 1979, Raveling 1984). Reductions of harvest outside Alaska and management of predator populations have increased growth rates of these populations with the exception of emperor geese, which have not responded to management. High levels of lead shot ingestion have caused severe declines of several species of sea ducks nesting on the Y-K Delta. These declines have caused one population, spectacled eiders, to be listed as threatened and brought about restrictions on hunting activity.

Arctic Pollution

The greatest concern about pollutants is that global change will enhance entry of pollutants into arctic food chains, ultimately contaminating subsistence foods. Global atmospheric circulation is transporting pollutants from temperate zone industrial areas into the Arctic. Additionally, substantial concern exists for transport of pollutants by river from Russian industrial areas directly into the Arctic Basin. Improved technology and declining tensions with Russia are allowing closure of numerous U. S. defense sites and concern exists among arctic residents about residual contaminants associated with these sites. Changes in sea ice distribution and storm patterns are likely to influence transport, although in unknown ways. Increased flooding may transport raw sewage from village sewage lagoons into subsistence food chains. Changes in hydrological patterns and storm systems may increase rates of release of naturally occurring toxicants (e.g., heavy metals or naturally occurring hydrocarbons).

Socioeconomic Changes

Economic and social changes in human societies both inside and outside the Bering Sea region have the potential to profoundly affect the region over time periods of decades or less. For example, development has substantially altered wintering habitat of many populations of waterfowl that nest in Alaska. For some populations of geese these changes have been beneficial, e.g., adoption of grain agriculture has improved overwinter energy balance and population dynamics for some populations. Oyster mariculture and industrial salt production in Mexico, however, could negatively impact brant nesting in Alaska.

Market processes driven by influences outside the Bering Sea region impact coastal and marine ecosystems and humans associated with these systems in the Bering Sea area. Salmon farming has increased the supply of salmon worldwide, substantially reducing prices of chum and other salmon. Reduced prices have had important negative economic consequences for commercial fishermen in the Bering Sea area. The massive factory trawler fishery in the Bering Sea has unknown consequences on nontarget fish stocks (bycatch) and other species of marine birds and mammals. Such effects could negatively impact coastal residents directly by reducing subsistence resources or indirectly because fishing or hunting activities are restricted under the endangered species act.

Oil reserves exist in the Bering Sea and Norton Sound, in addition to those on the north slope of Alaska. Economic or strategic concerns could, in the future, favor development of these fields. Such development would likely have a positive impact on the economy of the region, although it would bring about a shift to an increasing dependence on the cash economy and possibly reduced subsistence. Coastal areas of the Y-K Delta are among the potentially most sensitive in the world to oil spills because of high tidal energy, low topographic gradients, and productive grazing ecosystems that extend to the edge of the normal high tide line.

Understanding social and economic change in villages is of fundamental importance to understanding global change in the Bering Sea region. Employment is still very limited in many villages. Education is in flux as villages incorporate more traditional knowledge into the curriculum while seeking to improve learning of basic skills. Infusion of cash and availability of food in village stores has reduced the apparent importance of subsistence hunting and fishing in the minds of many young people. Some young people appear to prefer recreation in the village to traditional subsistence activities practiced by the generation preceding them. Rapidly expanding population is straining housing, infrastructure, and social institutions in many villages. A vigorous sovereignty movement is altering the relationship between state and federal governments and village residents. Responses of residents of the coastal areas in the Bering Sea region will impact the relationships between these people and coastal ecosystems. Likewise, the response to changes in resource extraction, commercial fishing, and other economic development will have important implications for sustainability of villages in the region.

9.4 Uncertainties

Uncertainties about impacts of global change in the Bering Sea region exist in the full range of projections from changes in climate and sea level to socioeconomic dynamics. Improving forecasts of climate are of fundamental importance; in particular, improved understanding of air temperature dynamics, storm surges, and sea surface temperature is essential for predicting climate-related impacts in the Bering Sea region. Forecasting cyclonic storm patterns by global climate models has improved, but additional refinement of temperature prediction is necessary.

Prevailing marine currents in the Bering Sea are reasonably well studied. Response of such currents to changes in prevailing winds and sea surface temperature requires additional study. Additionally, increased understanding of storm surges is necessary to predict the impact of rising sea level and increased storm activity on inundation and erosion of coastal areas. We have a poor understanding of coastal sediment transport, which could offset some erosion at the regional scale. At a minimum, it is important to use remote sensing to document changes in coastal geomorphology that have occurred over the last 4 decades.

Most trophic interactions, such as those between herbivores and plants or between predators and prey are too poorly understood to predict how global change will alter ecological communities and subsistence resources. For example, warming of the active layer is projected to increase plant growth which could either: (1) increase herbivore populations if food is limiting, or (2) reduce herbivore populations if increased carbon accumulation reduces forage quality. Marine ecosystems are even more poorly understood, and it is not currently possible to predict how changes in sea surface temperature, marine currents, and storm activity will affect these ecosystems. Of particular concern to subsistence hunters is the effect of changing ice dynamics on movements of and access to marine mammals.

Dynamics of the human population and socioeconomic changes will likely have major impacts on the Bering Sea region over the next few decades. Yet, understanding these changes has received relatively little attention. Changes in the size of the human population of the region alone will undoubtedly influence subsistence resources. We cannot currently predict whether greater employment opportunities will increase (because of increased cash flow) or decrease (because of reduced available time) subsistence harvest. Additionally, development of mineral extraction and industry in the Arctic has unknown consequences for subsistence resources. The current level of debate indicates our poor understanding of these relationships.

9.5 Additional Research Needed

Clearly, there is a fundamental need to improve our understanding of major climatic drivers including temperature, precipitation, and storm patterns. It is also important to improve understanding of how oceanographic variables such as sea level, temperature, currents, sediment transport, and ice dynamics will respond to climate change. Virtually all trophic interactions in both terrestrial and marine ecosystems require research if we are to predict how populations of important subsistence animals will change in the next few decades. Improving understanding of dynamics of animal populations used by subsistence hunters and likely impacts of global change on these populations will require coordinated efforts by population biologists, ecosystem scientists, climatologists, and oceanographers. Understanding ice dynamics and how animals are likely to respond to changes in ice distribution will be very important to residents of coastal areas of the Bering Sea region. It is important to understand how changes in hydrological patterns, marine currents, and water temperature might contribute to release of natural or anthropogenic contaminants.

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